

LCA Case Studies

Case Studies Examining LCA Streamlining Techniques

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Abstract

Pressure is mounting for more streamlined Life Cycle Assessment (LCA) methods that allow for evaluations that are quick and simple, but accurate. As part of an overall research effort to develop and demonstrate streamlined LCA, the U.S. Environmental Protection Agency has funded studies to examine the validity of various streamlining methods. Ten streamlining methods were identified and tested for accuracy against full LCAs. The objective of this effort was to identify streamlining methods that produced conclusions similar to those reached through full LCAs. Results of this evaluation showed that many streamlining methods give incorrect conclusions at least half of the time as compared to full LCAs. Streamlining will always incur the risk of obtaining results that are different than a full LCA. However, if some level of risk is acceptable, there are some general rules that can be used to select a streamlining method that will reduce the risk of serious error.

Keywords: Streamlined LCA studies, accuracy; streamlining methods, accuracy; product analysis, streamlined methods, LCA

1 Introduction

Life Cycle Assessment (LCA) is increasingly being used to evaluate the environmental performance of production systems. In practical terms, conducting a full LCA can be expensive and time consuming. This arises in part due to a lack of consensus among practitioners on all LCA issues and techniques, and, importantly, due to a lack of reliable and comprehensive publicly available data sources. These issues have resulted in a great interest in streamlining methods for LCA. In this paper, we refer to streamlining methods as any measure or procedure taken to reduce the scope, cost, and effort required to conduct the LCA. However, consensus has not been reached on the definition of a streamlined LCA, methods and procedures that should be used in a streamlined LCA, or appropriate uses of a streamlined LCA.

Streamlining methods that have been suggested and are currently being used have been reported in the literature [1,2]. Despite the great interest in streamlining, there has been no research to systematically evaluate the effects of streamlining methods on LCA results. None of the streamlining methods have been systematically evaluated for validity as a replacement for a full LCA. The purpose of the analysis summarized in this paper was to evaluate different streamlining methods to determine which methods result in the same overall directional conclusions (i.e., ranking of product systems) as a full LCA.

2 Research Methodology

For this analysis, streamlining methods identified as part of previous research [1] were applied to sets of baseline Life Cycle Inventory (LCI) data for a variety of product systems. First, full LCI data were used to draw comparative conclusions about the product systems in several product groups. Then each streamlining method was applied to the LCI data for each product system, and new conclusions were drawn based on the results of the streamlining method. Results obtained from the application of the streamlining methods were then compared against the results obtained from the full LCIs to determine the effects of streamlining. The success of each streamlining method was measured in terms of how well the product system rankings based on the results of the streamlined LCIs matched those based on the results of the full LCIs.

2.1 Case study systems analyzed

Existing and newly developed LCI data were employed for baseline data. LCIs from Franklin Associates served as the primary source of this baseline data. The case study systems are listed below by product category using a code label. For example, three retail food containers were evaluated; these are listed as RFC1, RFC2, and RFC3.

- Retail Food Containers: RFC1, RFC2, RFC3
- Industrial Chemicals: IC1, IC2
- Secondary Packaging: SP1, SP2
- Consumer Packaging: CP1, CP2, CP3, CP4
- Fluid Containers: FC1, FC2, FC3, FC4
- Food Service Products: FSP1, FSP2, FSP3
- Household Liquid Products: HLP1, HLP2

Products in each category were compared on an equivalent basis. This means that each of the RFCs delivers the same quantity and quality of food to the consumer; each of the ICs delivers the same level of service to the consumer; and so on.

Similar streamlining studies on three additional product categories have been performed by Research Triangle Institute [5,6,7]. The results are consistent with the findings reported here, and will be reported in detail later.

2.2 Procedures for implementing streamlining methods

Table 1 is a summary of the streamlining methods applied in the case studies. They are designated by the letters A through J. These methods can be grouped into three general types. Methods A through D, I, and J are all approaches that reduce the scope of the LCA by excluding classes of materials. Methods E, F, and H reduce data needs by substituting surrogates for data that may not be readily available to the practitioner. Method G reduces data needs by substituting qualitative or less accurate data where better data are not available.

Each streamlining method was applied to the LCI of each product. Within each product group, the products were ranked based upon a number of LCI parameters. The rankings were established on as many as eight energy categories, six solid waste categories, 20 to 25 air emission categories, and 25 to 30 water emission categories. As an example, the

Table 1: Summary of procedures for applying streamlining methods

Streamlining Method		Application Procedures
A	Removal of Upstream Components	All processes prior to primary ¹ material manufacture are excluded. Includes fabrication into a finished product, consumer use, and postconsumer waste management.
B	Removal of Partial Upstream Components	All processes prior to primary material manufacture are excluded, with the exception of the step just preceding primary material manufacture.
C	Removal of Downstream Components	All processes after primary material manufacture are excluded.
D	Removal of Up- and Downstream Components	Only primary material manufacture is included. Sometimes referred to as a "gate-to-gate" analysis.
E	Specific Entries Used to Represent Impacts	Selected entries are used as proxies for 24 impact categories based on mass and subjective decisions—other entries within each category are excluded.
F	Specific Entries Used to Represent LCI	Search for specific entries from segmented LCI that correlate highly with full LCI results—other entries are excluded.
G	Use of Qualitative or Less Accurate Data	Include data for processes that dominate results, based on initial screening LCI; other process steps qualify for less accurate data or are excluded.
H	Use of Surrogate Processes	Selected processes were replaced with apparently similar processes based on 1) physical, chemical, or functional similarity to the data sets being replaced; and/or 2) availability of data in Franklin Associates' private database.
I	Limit Raw Materials (<10 %)	Raw materials comprising less than 10% by mass of the LCI totals were excluded.
J	Limit Raw Materials (<30%)	Raw materials comprising less than 30% by mass of the LCI totals were excluded.

¹ Examples of primary material manufacture are polymerization of a plastic, smelting of a metal, etc.

three products in the group called retail food containers could be ranked based upon total energy using a full LCI. Then, as each streamlining method was applied, the ranking obtained using that method was compared to the ranking based on the full LCI.

Ten streamlining methods (listed A through J in Table 1) were examined for twenty products organized into seven different product categories. Table 2 provides an overall summary of the success of each streamlining method for each category. Success is measured as the percent of time that the streamlining method resulted in the same ranking of products (within each product group) as the full LCA. Findings by streamlining method are as follows:

(2) Streamlining method B: removal of partial upstream components

Table 2 shows similar results for this method and Method A. The overall quality score is higher, indicating that overall Method B worked about two-thirds of the time. Including an extra upstream step made the analysis more complete; thus, there were generally more matches with the full LCA rankings. However, the range is about the same, and the highest and lowest scores occur for the same product systems. This result is not surprising. In most product systems, the major energy consumption and the air and water emissions tend to be larger in raw materials acquisition and manufacturing stages, rather than in those stages subsequent to primary material manufacture.

Table 2: Results summary matrix (measures of success, in percent)

Product Category	No.	A	B	C	D	E	F	G	H	I	J
RFC	3	43	60	60	22	46	19	--	--	70	42
IC	2	52	92	100	43	92	69	--	--	--	--
SP	2	98	99	92	90	89	73	--	--	97	98
CP	4	32	39	80	19	52	19	--	--	60	51
FC	4	42	60	33	8	36	6	--	--	88	61
FSP	3	75	80	40	47	42	16	--	--	99	64
HLP	2	64	64	64	20	57	36	--	--	83	83

(1) Streamlining method A: removal of upstream components

In this method, all steps prior to primary material manufacture are excluded. Examples of primary material manufacture are polymerization of a plastic, smelting of a metal, etc. Table 2 shows that the average success of this method for all product categories is about 58%. The table also shows that there is a wide variation in the success of this method for different product systems. The measure of success ranges from a high of 98% for secondary packaging to a low of 32% for consumer packaging. The reason that this method works quite well for some products and not for others is explained quite easily, and is predictable. Because this method excludes all processes prior to primary material manufacture, the method works well for those product systems where the LCI totals are dominated by primary material manufacture. The roles of reuse and recycling also affect the results. The consumer packaging category contains a recycled product and the food service products category has two reused products. Using Method A, it is important to note that the recycled product loses the advantages of reduced upstream requirements, but retains the added burdens of recycling, such as collection, transportation, and reprocessing. As a result, the ranking of the recycled system relative to the non-recycled systems changes significantly.

(3) Streamlining method C: removal of downstream components

Overall, the success rate for this method is also about two-thirds. Once again, the range of success values is very large, from 33 to 100. For four of the product categories (retail food containers, industrial chemicals, secondary packaging and household liquid products), the success was about the same as for Methods A and/or B, while success improved for consumer packaging and decreased for fluid containers and food service products. This method still includes the primary material manufacturing stage; thus, it is successful for those systems in which primary material manufacture dominates the environmental emissions and resource use. For systems in which the primary material manufacturing stage is not dominant, the results of streamlining Method C are much more variable.

(4) Streamlining method D: removal of up- and downstream components

This method focuses on the material manufacturing stage only, as is often referred to as a "gate-to-gate" analysis. The success rate is only about one-third, and is the least successful of all of the streamlining methods. In only one product category – secondary packaging – was the success greater than 50%.

Table 3: Results summary matrix – approach E (measures of success, in percent)

Selected Impact Subcategory	Representative Entry	Product System							Average Quality Score
		RFC	IC	SP	CP	FC	FS	HLP	
Fossil Fuel Depletion	Total Fossil Fuel	50	100	100	50	50	50	50	64
Landfill Space	Total Solid Waste Volume	0	75	100	75	25	75	75	61
Greenhouse Gas	Carbon Dioxide	25	75	100	50	25	25	50	50
Acid Rain Precursor	Sulfur Oxides	100	100	100	67	33	33	67	71
Human Carcinogen	Chromium	50	100	50	50	50	50	50	57
Respiratory System Effects	Particulates	50	100	83	17	33	17	50	50
	Average Quality Score	46	92	89	52	36	42	57	59

Source: Appendix Table E-9 [3]

(5) Streamlining method E: specific entries used to represent impact categories

This method examines impact categories, which include fossil fuel depletion, landfill space, and human health and ecosystem quality categories. For each impact category, the possibility was examined that one entry could be used as representative or as a surrogate of that category. For example, the human health subcategory of respiratory effects includes six emission entries. From these six entries, particulates was chosen to be the representative entry for respiratory effects. Within the respiratory effects subcategory, the number of entry rankings that matched the ranking for particulates was expressed as a percentage. For example, if two out of five entries in the respiratory effects subcategory matched the ranking of particulates, the success rate was $2/5 \times 100\%$, or 40%. Over 25 impact categories, most consisting of multiple entries, were analyzed in this manner for each product system.

Table 3 is a sampling of the results for Method E (more complete results are presented in [3]). It shows, as examples,

representative entries for six of the 25 impact subcategories. The average quality score is only 59%, with a range of 50% to 71%. Thus, the method had a low degree of success for the various impact subcategories. Looking at the product totals, this method achieved relatively high scores for two product groups. The two product groups are industrial chemicals and secondary packaging. Those are both two-product groups, with one product dominating for most entries, so this result is not surprising. Otherwise, the average success rate was only about 50%.

(6) Streamlining method F: specific entries used to represent LCI

In this method, a search was made for individual inventory entries that could be used as a surrogate to represent other entries. For example, suppose that one of the eight types of energy was used as a surrogate for total energy. Table 4 shows that the same product ranking would occur in only 32% of the cases. The discussion of Method F in [3] shows that this is a very complex and extensive analysis with little predictable correlation between various entries, which is

Table 4: Results summary matrix – approach F (measures of success, in percent)

Selected Inventory Entries	Product System							Average Quality Score
	RFC	IC	SP	CP	FC	FS	HLP	
Total Energy	8	69	73	25	8	2	39	32
Total Solid Waste	17	69	73	25	8	2	39	33
Particulates	36	69	73	8	10	12	36	35
Sulfur Oxides	36	69	73	25	5	36	39	40
Biochemical Oxygen Demand (BOD)	11	69	73	25	5	36	39	37
Lead (waterborne)	5	69	73	8	1	7	25	27
Average Quality Score	19	69	73	19	6	16	36	34

Source: Appendix Table F-10 [3]

Table 5: Summary of results – approach G (use of qualitative less accurate data)

Product System Group	Abbrev.	Percent of Process Steps which Qualify for Using Less Accurate Data ¹⁾							
		Raw Materials	Intermediate Materials	Primary Materials	Final Product	Recycling	Reuse	Sec./Ter. Packaging	Waste Management
Retail Food Container 1	RFC1	100%	67%	100%	0%	na	na	na	0%
Retail Food Container 2	RFC2	100%	91%	100%	0%	na	na	na	100%
Retail Food Container 3	RFC3	86%	82%	100%	100%	na	na	na	0%
Industrial Chemicals 1	IC1	100%	80%	100%	100%	na	na	na	0%
Industrial Chemicals 2	IC2	100%	73%	0%	100%	na	na	na	100%
Secondary Packaging 1	SP1	100%	100%	50%	0%	100%	na	na	100%
Secondary Packaging 2	SP2	100%	50%	na	0%	na	na	na	0%
Consumer Packaging 1	CP1	100%	78%	0%	0%	na	na	na	0%
Consumer Packaging 2	CP2	0%	0%	0%	0%	na	na	na	0%
Consumer Packaging 3	CP3	na	67%	na	0%	0%	na	na	100%
Consumer Packaging 4	CP4	100%	33%	0%	100%	na	na	na	0%
Fluid Containers 1	FC1	100%	78%	100%	100%	na	na	50%	100%
Fluid Containers 2	FC2	100%	100%	na	0%	na	na	50%	100%
Fluid Containers 3	FC3	100%	100%	0%	0%	na	na	50%	100%
Fluid Containers 4	FC4	75%	88%	100%	na	na	na	na	100%
Food Service Products 1	FS1	100%	na	0%	na	na	0%	0%	100%
Food Service Products 2	FS2	100%	89%	100%	na	na	0%	100%	100%
Food Service Products 3	FS3	100%	90%	50%	0%	na	na	na	0%
Household Liquid Products 1	HLP1	100%	94%	75%	100%	na	na	0%	0%
Household Liquid Products 2	HLP2	80%	90%	50%	100%	na	na	50%	100%

¹⁾ A process step that qualifies for using less accurate data is defined here as a process step for which a 25% change in most (all but 3 or fewer) data points causes less than a 10% change in the corresponding inventory total
na means not applicable

Source: Franklin Associates, Ltd. [3]

illustrated by the summary information in Table 4. In some cases, such as the industrial chemicals and secondary packaging product groups, there is a fairly reproducible correlation, but for other products this is not true. As discussed before, this is predictable for the two-product group secondary packaging in which one product dominates in almost every respect. Industrial chemicals is also a two-product group in which one product is dominant. For the other product groups, the correlations are generally quite low, less than 40%.

(7) Streamlining method G: use of qualitative or less accurate data

In this method, a search was made of the LCI results to locate data which contribute little to the final result. This is a variation on the historical method of using sensitivity analysis on LCI results to identify processes that are the most or least important. Each of the 20 products studied was disaggregated into eight subprocess steps: raw materials, intermediate materials, primary materials, final product, recycling, reuse, secondary and tertiary packaging, and waste management (→ Table 5). Subprocess totals were calculated and compared to the LCI totals for each LCI entry. Table 5 shows example results, using the arbitrary qualification that for each process step to qualify for less accurate data, a 25% change in an individual value would change

the LCI total by less than 10%. For example, the results for retail food containers 1 (RFC1) in Table 5 show that, for all of the raw materials (100%), a 25% change in the data would result in a change of less than 10% in the LCI total. However, none of the final product steps fall into this category (i.e., a 25% change in any final product data would change the LCI total by more than 10%).

For those subprocesses that contribute little, the data quality requirements can be made lower than for subprocesses that contribute much more to the total. The implication here is that, using these criteria, estimates for the raw materials steps may be adequate, but the final product steps must use high quality data. The table shows that the search for subprocesses in which less accurate data can be used must be done very carefully. For example, in many cases primary materials manufacture is a dominant process step, but for seven out of 20 products in Table 5, 100% of primary material steps qualify for less accurate data.

This is one of the most promising approaches, but care must be taken to establish what process steps qualify for less accurate data. A desired threshold level must first be established. Then a complete, screening-level LCI needs to be performed. A complete flow diagram must be developed, with materials flow quantities in place. Use of reasonable

estimates can be used where good data are not found. Each process can now be represented by the best data available to the practitioner. If primary data are not available, secondary data or even generic data from commercial databases can be used. A preliminary, but complete, LCI is performed at this point. If desired, the components of each product system can be divided into process steps as was done in the example here.

Then a sensitivity analysis is applied. In this process, each LCI entry is examined and the percent contribution of each process to the total is calculated. For those processes which contribute a large percentage of the total, the best data possible is required. Generic data or estimates will not be sufficient. For those processes that contribute very little to the total (for example less than 1%), estimates or surrogates are acceptable. This process also leads to an analysis of product system structure, which is also an aid to selecting valid streamlining approaches.

(8) Streamlining method H: use of surrogate processes

Sometimes an LCI practitioner needs data on a chemical process for which data are not readily available. This streamlining process addresses the possibility of using a similar chemical process for which data are available. For example, if propylene glycol data are needed, perhaps data could be used for ethylene glycol, which is certainly not identical but is chemically similar. Table 6 shows three selected comparisons. One of the three works well; the other two do not. Franklin Associates [3] summarizes 40 calculations and reports the percent of entries that are within 10% of those from the original full LCI for that product. Their results show the common occurrence that the surrogate process changes results by more than 10%. In the case of total energy, for example, this is true for 14 of the 40 entries (35%). There is no consistent success either by product, or by entry category.

Table 6: Comparison of total energy for selected surrogates

	million BTU	% Difference
LDPE Plastic	41.1	
PP Plastic	38.3	7
Ethylene Glycol	115	
Propylene Glycol	194	51
Semichemical Paper	8.4	
Unbleached Kraft Paper	15.2	58

Source: Appendix Tables H-26, H-28, H-29 [3]

(9) Streamlining methods I and J: limit raw materials

Methods I and J are very similar. Method I excludes all raw materials (including any intermediate processing of those materials) that do not individually comprise at least 10% by mass of the total of raw materials, and Method J excludes all raw materials that do not individually comprise 30% by mass. Method I is overall the most successful method studied, with a quality score of 83% (→ Table 2, p. 38).

However, imbedded in that total is one product category at 60% (consumer packaging). Thus, even this technique needs to be approached with caution. Method J is overall less successful, owing to the greater amounts of raw materials excluded. However, two systems (secondary packaging and household liquid products) have the same quality score for both I and J. The reason for this is that in these particular products there are no raw materials required that fall in the range of 10% to 30% of mass.

3 Summary of Overall Findings

In this analysis, a search was made for principles and guidelines for performing streamlined LCA studies that could be applied to new product categories for which there is limited knowledge, but that would yield results of acceptable quality. Overall findings from this analysis are summarized below:

- Methods A through D highlight that a full life cycle approach is necessary to reach valid conclusions about comparative resource and environmental results. The more process steps (and data) that are included in the streamlining method, the higher the likelihood of success in matching full LCA conclusions. Even in systems where the primary material manufacturing step may be very important, neglecting the entire life cycle can easily lead to erroneous conclusions. Methods that exclude large classes of data were predictably quite unsuccessful.
- The success of streamlining methods was generally not predictable for different product categories. For some products one method would work quite well, but another method would not. This dictates a careful analysis to determine the product system characteristics that will allow us to predict what streamlining scenarios work best. An exception was the secondary packaging product group, and, to a lesser extent, the industrial chemicals product group. Both of these product groups consisted of only two products, and the full LCI showed that one product required more resources and produced more emissions in almost every inventory entry. Method I, where raw materials that comprise less than 10% of the total of all raw materials were excluded, was the most successful method recorded in Table 2, but the quality scores were generally less than 90% for 67% of the products. If this method is to be acceptable, the threshold for exclusion would need to be well under 10%.
- The search for correlations between inventory entries that would allow use of surrogate data (Method H) to replace more complete and detailed data was generally even more unsuccessful than the other methods studied. No general rules leading to reasonable success were found, except in areas where one particular value in a group was clearly a dominant value. Substitution of surrogate process data

to replace primary data appears to be valid only if the surrogate processes very closely resemble the actual processes, or if the processes contribute very little to LCI totals.

- The single method with the most promise appears to be Method G, use of qualitative or less accurate data. This method involves looking at an entire product system, and finding which parts of the system contribute very little to the totals. These parts can then be eliminated, or semi-quantitative estimates can be used without significantly affecting the LCI conclusions. In many cases, a given process component may contribute some small value, such as less than 1% to a total, which means that this process is a candidate for substitution of surrogates or for estimates.

4 Conclusions

The search for streamlining methods through this research shows that great care needs to be exercised. Most streamlining methods gave incorrect ranking of products at least half of the time or more as compared to full LCIs. This is unacceptable given that the primary application of LCAs is to make comparative assertions between alternative product systems. Common practice dictates that success requires a process that will give correct conclusions at least 80% of the time, with 90% to 95% being even more preferable.

Results from our analysis were often unpredictable, thus making it impossible to guarantee results based on a particular type of streamlining method. The validity of individual streamlining methods can only be judged on a case-by-case basis because it depends on the product systems being studied, quality of the data, and purpose of performing an LCA. This is not to imply that streamlining is always undesirable or useless, but does point out that the results can often be so different that the streamlined version bears little or no resemblance to the original LCA. In such cases, it may be appropriate to recognize that the streamlined version is no longer an LCA, although it can still be used for important conclusions and analyses regarding those materials and processes that are included in the streamlined version.

The most successful method studied was essentially the historical "sensitivity analysis" approach. This requires that a model of the entire product system to be studied must first be determined using reasonable estimates where good data are not found. A preliminary, but complete, LCI is performed at this point. Sensitivity analysis can then be applied to examine the percent contribution of each process to the LCI total. For those processes which contribute a large percentage of the total, the best data possible is

required. For those processes that contribute very little to the total (e.g., less than 1%), estimates or surrogates are acceptable. This process also leads to an analysis of product system structure, which is also an aid to selecting valid streamlining methods.

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This work has not been subjected to Environmental Protection Agency review. Therefore, it does not reflect the views of the Agency.

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